IMPROVE PRODUCTIVITY AND REDUCE OPERATING COSTS BY USING AN INTEGRATED APPROACH TO ACHIEVE SUPERIOR ENERGY-EFFICIENT BUILDINGS

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Introduction

Designing and building superior energy-efficient buildings and retrofitting existing buildings in an integrated and very energy-efficient way can reduce energy-related operating expenses by 30 to 60 percent and more. Such savings translate into as much as $0.50 to well over $1.00 per square foot and represent one of the largest controllable operating costs in a building. However, achieving such success is challenging. It will take significant changes in the way buildings are typically designed, constructed and remodeled. "The way things are always done" can no longer be the norm if superior energy efficiency and the resulting operating cost savings are the goals.[1]

In new construction, the process of designing and building a superior energy efficient building integrates design solutions relative to occupant needs as well as all building systems, including the architecture (windows, daylighting, insulation, interior space utilization), lighting, mechanical systems, control systems and "plug loads" (such as computers and printers). In addition, building operations and maintenance is a critical element that should be considered in the early design phases. Other elements of a superior energy efficient building process include commissioning and post-occupancy evaluations.

In existing buildings, the integration of various building systems as described above is also crucial to achieving superior energy efficient retrofits. Taking the opportunity to re-examine buildings for energy-efficiency opportunities is usually lucrative. However, if done in a component-driven rather than an integrated approach, opportunities will inevitably be lost.

The Benefits Of An Integrated Building Systems Approach

Before discussing the process for achieving superior energy efficiency, it is helpful to understand why a systems approach is important and what differentiates it from the standard approach to building design. An integrated building systems approach provides the following benefits:

1. **Energy efficiency reduces operating costs and increases profitability.** In an existing large office building, an integrated approach was estimated to save as much as forty percent of the utility costs. Implementation of selected energy-efficiency measures (EEMs) would provide an internal rate of return of 17 to 22

percent, higher than the company's discount rate. Had an integrated approach not been taken, it is likely that the owners would not have understood that their chiller plant was significantly oversized for their load requirements and that they could downsize their chillers while at the same time increasing chiller efficiency.

In a new Chicago university building, an integrated approach was estimated to save the university about one third of the building's originally estimated utility bill through use of high-quality energy-efficient lighting, more efficient air handling and air distribution systems, use of gas absorption chillers rather than electric chillers and an energy management system. The integrated approach pointed out the importance of various assumptions relating to occupancy, lighting and plug loads that significantly reduced the required loads in the building and led to decreased chiller size. In addition, the building received a much higher quality lighting system than originally envisioned.

In other large office buildings, where only low-cost and no-cost measures have been implemented, savings of 5 to 10 percent of the utility bill have been realized.

2. **Energy efficiency can sometimes reduce first costs.** In the university building cited above, lighting system first cost increased but chiller system first cost decreased because the chiller could be substantially downsized -- by at least 200 tons. This easily paid for the lighting upgrade.

   In another example, a tenant in a new space was able to avoid 100% of the cost of installing supplemental cooling by installing energy-efficient fluorescent lighting using T8 lamps and electronic ballasts. First cost savings were close to $90,000 in a 60,000 square foot space. The payback was immediate and lighting quality was improved.

   A 650,000 square foot office building in Chicago was seriously considering installing a new chiller to make up for capacity problems (not enough cool air) during peak summer days. After an operations and maintenance audit was performed, it was determined that there might be other problems causing the perceived low chiller capacity. Not only would those maintenance problems, once solved, eliminate the need for the $200,000 cost of a new chiller, utility costs dropped because the maintenance repair reduced the air handling requirements of the building.

3. **An integrated approach can increase comfort which in turn can boost employee productivity.** A recently published book by Joe Romm entitled Lean and Clean Management describes a number of cases where increased productivity has been documented. Because the largest cost of operating a building is usually the salaries of the employees, productivity increases usually more than pay for the energy efficiency upgrade.[2]

The following are some examples cited in Romm's book:

- A new engineering facility built for Lockheed uses daylight to provide much of the ambient lighting. The building saves about $300,000 to $400,000 per year on energy bills. At the same time productivity rose 15 percent after the employees moved in.

- Boeing installed energy efficient lighting in one of its existing plants, reducing energy consumption for lighting by up to 90 percent. In addition, glare is reduced with the new, higher quality lighting system helping workers to reduce defects.

- A lighting and ceiling retrofit at the Reno Post Office, which cost about $300,000 to install and resulted in energy and maintenance savings of about $50,000 per year, helped employee productivity by reducing machine operator errors to 0.1 percent, about a 6 percent productivity gain. This productivity gain was worth over $400,000 per year, more than paying for the remodel in less than a year.

Most productivity gains have not been quantified. Those listed above are unusual. However, it is undeniable that some new energy-efficient technologies improve the quality of the work environment. Such technologies include T8 lamps and electronic ballasts which do not hum and flicker and have much better color rendition than the old T12 lamp and magnetic ballast technology.

4. **An emphasis on energy-efficiency can lead to better long-term results.** An energy efficiency program includes commissioning and other processes, such as preventive maintenance, that can reduce costs in the long term. Few buildings are commissioned before they are put into service. This means that the building operators spend at least the first year or two working out the "bugs." Commissioning was performed at the university building cited above and saved the university years worth of air handling system balancing and other work. It also allowed the university to withhold payments to contractors until they were assured that work was completed to their satisfaction.

5. **Energy efficiency leads to pollution reduction.** The US Environmental Protection Agency has determined that four percent of annual carbon dioxide emissions, seven percent of sulfur dioxide emissions and four percent of nitrogen oxide emissions from all US power plants could be eliminated if the Fortune 1000 companies profitably retrofit 90 percent of their existing lighting systems in their owned and leased real estate. This reduction in polluting emissions, in turn, could eliminate or postpone the need to build new power plants. This example only illustrates the potential results from lighting upgrades; mechanical system upgrades can provide additional savings.

6. **Many energy efficiency measures have little risk.** Returns from their implementation are safer than putting money in the bank at 5%. For instance, if appropriate assumptions for operating hours are made, a lighting retrofit will provide a guaranteed level of savings. It is relatively simple to calculate exactly how much energy such a retrofit will use.

The Process Of Designing/Retrofitting Buildings To Be Energy Efficient

In many ways, the process for designing superior energy-efficient buildings may not seem that different from the standard design process. For new buildings, the process will still include the standard steps of Programming, Schematic Design, Design Development, Construction Documents, Bidding and Negotiations, Construction and Commissioning. The difference is in the use of more feedback loops and the commitment by all parties, including the owner, designers, engineers, construction manager and others to a process of designing a superior energy efficient building. Note that this has rarely been done and, even in this paper, cited examples have generally only benefited from a portion of the process. A further difference is the inclusion of a Design Assistance Professional (DAP) who is responsible for the energy efficiency agenda.[3] This person (or team) is important because the architects and engineers may not be aware of the latest energy efficient technologies or processes, nor are they generally able to do the computer modeling that is necessary to understand the interactive effects of energy efficiency measures and to best perform life cycle cost analyses. It is also extremely helpful to have an energy efficiency "watchdog" who keeps all parties communicating with each other regarding the energy goals and objectives.

Understand Building Use

The first step toward designing or retrofitting energy-efficient buildings is to understand how the building will be or is being used and the type of equipment that is planned as this will affect both its design and energy consumption. For an office space, for instance, this may seem straight forward; after all, it may seem that all office spaces have much in common. However, it is important to understand the tasks that people will perform in the office space. Do they include mostly data entry, writing, reading, drafting, meetings, computer-based or paper-based tasks, etc.? Will there be partitions (how high?) or private offices? What is the average age of the employees? What kind of equipment is the purchasing department specifying? Have they considered efficient computers and printers, such as those with the US EPA's Energy Star logo? Answers to these and other questions will affect the design and subsequent energy consumption.

For an existing building, it is also important to know how the building has been operating. Are there comfort complaints? When, how often, in what locations? Do these complaints relate to temperature, indoor air quality? Determining the load profile, through graphing of utility bills can often provide some useful information as well. An important question is, what kind of changes are expected in the near and medium term future? To answer some of these questions in an existing building, a detailed energy audit is generally performed.

Understand Systems Interactions

Once building use is determined, understanding how each of the systems in a building interact with one another is the key to an integrated whole systems approach. Saving energy using an integrated approach generally involves making sure that all opportunities are explored and as few as possible are lost. Lost opportunities can occur, for instance, when a chiller or air handling unit retrofit is completed prior to performing a load reduction retrofit such as an energy-efficient lighting upgrade. This happens all too often when a consultant is hired to design a specific new component without being asked to look at the interactive effects of that component in relationship to the entire building.

Use an Hourly Energy Simulation Model

An integral part of the process of designing superior energy-efficient buildings is the use of an hourly simulation computer model. Such a computer model allows the designer to understand the interactive effects of a large number of systems and allows quantification of energy saving benefits of individual EEMs and groups of EEMs prior to spending the capital to install systems. This tool provides an understanding of the implications of various decisions and helps maintain quality. However, as with all computer models, an hourly simulation model is only as good as the data used, the assumptions made and the modeler's knowledge of building systems.

The simulation model should be used early in the design phases. In a new building, it would typically be developed in the schematic design phase and used through to commissioning. In an existing building analysis, it is used as a tool to determine the feasibility of various EEMs. In the commissioning process, the model serves as a valuable tool for aiding the process, optimizing building performance and for documenting the successful performance of the adopted EEMs. In addition, once this model exists, it will allow the owner to answer questions regarding future EEMs and operational changes, ensuring the best possible energy-efficient systems.

A Process for Evaluation and Implementation of Energy-Efficiency Measures

The following list gives a recommended order in which to evaluate and implement energy-efficiency measures:

1. **Explore and implement operations and maintenance (O&M) opportunities.** This is most important for existing buildings, although discussions with the future operators of new buildings, while those buildings are being designed, can avoid greater energy consumption later. While investigating O&M opportunities, identify capital and control system improvements, including EEMs that could lead

to further savings.

An operations and maintenance audit can often result in savings of over 10% of the annual utility bill. Implementing operations and maintenance measures as a building evaluation is under way leads to immediate successes that can help justify further work. This may, for instance, include changing the way systems are controlled. In a 650,000 square foot Chicago office building, simply closing an outside air damper for the lobby air handling system was estimated to save about 4% of the building's utility costs per year because of a significantly reduced need to heat the outside air. Implementation of this measure has little or no cost yet the savings may be used to help pay for other more expensive yet lucrative EEMs.

2. **Reduce heating and cooling loads; check assumptions.** Heating and cooling loads are increased and/or decreased because of building envelope design, exterior features such as landscaping and internal loads such as lighting and equipment. When internal building loads are reduced in both retrofit and new applications, equipment used for heating and cooling may be downsized where appropriate.

   Taking advantage of reductions in heating and cooling loads is only successful if the assumptions used to calculate sizing of mechanical systems actually take such reduced loads into account. It is quite common to find high assumptions being made for lighting and "plug" loads which simply cause equipment to be oversized. This has even been true where loads were intentionally reduced.

   For instance, a common load assumption for new offices is 6 watts/square foot for lighting and plug loads. Since lighting is commonly about 1.2 watts/square foot or less with new fluorescent technologies, that leaves 4.8 watts/square foot for plug loads. In surveys we and others have conducted, 1.5 watts/square foot, even with the high use of computers and printers, is much more common. While sizing for 2.7 watts/square foot does not provide a necessary margin of safety, 6 watts/square foot will often lead to significant overdesign which is typically compounded as other margins of safety are added as the design progresses. In a 650,000 square office building that we surveyed in Chicago, one of three equal-sized chillers has never been used even though the building is over 95% occupied!

3. **Use low energy consumption methods for heating and cooling where possible.** One of the most commonly used low energy forms of cooling is the economizer which allows for the use of "free" cooling. In addition, other low energy heating and cooling systems that may be appropriate include taking advantage of solar gains in winter and using natural ventilation, evaporative, absorption and desiccant systems for cooling. In general, this is easier in new buildings, but may be appropriate for retrofits as well. For instance, where roof top air conditioners are used, indirectly evaporatively cooling outside air before it enters the rooftop unit can provide lucrative savings, especially in areas with high outside air

requirements.

4. **Explore specific mechanical and electrical system energy efficiency measures.** Specific measures include air handling system upgrades, more efficient cooling equipment, the addition of variable speed drives to motors, more efficient and carefully-sized motors, use of various types of efficient chillers including consideration of natural gas chillers and a host of other measures.

   One of the greatest areas of inefficiency comes from oversizing of these systems. (Could that be because it is difficult to sue anyone for overdesign?) Oversizing causes problems because systems operating at part load are generally inefficient. In addition, systems sized more closely to the load have a lower capital cost, potentially allowing more resources to be spent on the design process. With a cooling system cost per ton of over $1000, more accurate sizing can lead to significant savings. In addition, more accurately sized systems avoid control difficulties that occur because of higher temperature and humidity swings and avoid additional wear and tear on equipment that occur because of cycling.

5. **Add and/or improve control systems.** Changes in control strategies should also be part of an O&M review of building operations. Additional points of control or the addition of an entire energy management system may cost-effectively maintain the savings identified in an energy-efficiency upgrade or design. In most buildings, controls are not utilized to their capacity. Once installed, determining how to use them most effectively is relatively inexpensive.

6. **Commission the retrofit systems or building** and provide regular maintenance. Commissioning includes pre-functional testing and checking of systems. On project completion, it includes functional commissioning of systems, proper operations and maintenance documentation and training. Commissioning saves utility costs, time and aggravation in the long term as evidenced by the experience of the Chicago university building.

Conclusion

As the examples and process cited above illustrate, designing buildings for superior energy efficiency is an iterative process that integrates the work and knowledge of all of the stakeholders in a building design. Few buildings have been built according to all of the guidelines in this paper. Those that have used at least some of these principles have realized significant energy savings and high quality, highly productive environments. The potential continues to exist for much higher levels of savings and much higher quality work environments.

Several principles are important to understand:

- Design for the client's needs. If a building does not meet their needs, it will not save operating costs no matter how energy-efficient it is.
- Use an integrated approach. Such an approach avoids lost opportunities and has the greatest chance to result in a superior building, not just an energy-efficient building.
- Big changes will not happen overnight. This needs to be an iterative process that is based on the experience of committed owners, designers and all other members of the construction process.

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